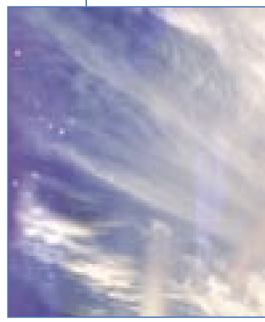


1 Introduction

NASA's Earth science programs are essential to the implementation of three major Presidential initiatives: Climate Change Research (June 2001), Global Earth Observation (July 2003), and the Vision for Space Exploration (February 2004).

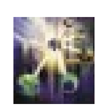
1 Introduction

The NASA vision is—
To improve life here
To extend life to there
To find life beyond

The NASA mission is—
To understand and protect our home planet
To explore the Universe and search for life
To inspire the next generation of explorers
…as only NASA can.

The Earth is the only harbor for highly diversified life yet found in the universe. In contrast to its neighbors Mars and Venus, Earth's atmosphere shields our planet to maintain an environment conducive to life and human civilization. What are the underlying features and processes that enable life on Earth? How are these sustained? Are they replicated in part or in whole elsewhere in the universe?

Perhaps more than any other human activity, several centuries of progress in flight have steadily changed our perception of the Earth as a home planet. Viewing the surface from aloft and now the entire planet from space, we recognize that land, seas and ice are each rich, constantly changing mosaics variously suitable for life. Adding satellite measurements of essential characteristics to stunning images from space, we have come to understand the Earth as a system of tightly coupled parts. It is now clear for example that the characteristics of Earth's atmosphere so critical to human habitability are maintained by complex and tightly coupled circulation dynamics, chemistry, and interactions with the oceans, ice and land surface; all driven by solar radiation and gravitational forces.



From the vantage point of space we also see at continental and planetary scales the vast extent and complexity of human activities. Over the past 50 years, world population has doubled; world grain supplies tripled; and total economic output grew sevenfold. From space, we see that expanding human activities now affect virtually the entire land surface and are altering world oceans and ice masses as well. Over the next 50 years, the world population is likely to grow to 11 billion, exerting ever more demands for habitable land and natural resources.

Thus, we live on a planet undergoing constant change due to natural phenomena and our own activities, and to maintain quality of life on Earth, we need continuous observations of variability and change over its entire surface analyzed to reveal the forces involved, the nature of the underlying processes and how these are coupled within the Earth system. To inform management, decisions, and policies, we need ongoing predictions derived from Earth observations to expose the responses that determine further change. Thus, NASA's mission in Earth science is to understand and protect our home planet by using our view from space to study the Earth system and improve predictions of Earth system change. The fundamental question:

> How is the Earth changing and what are the consequences for life on Earth?

expresses the strategic goal of this effort.

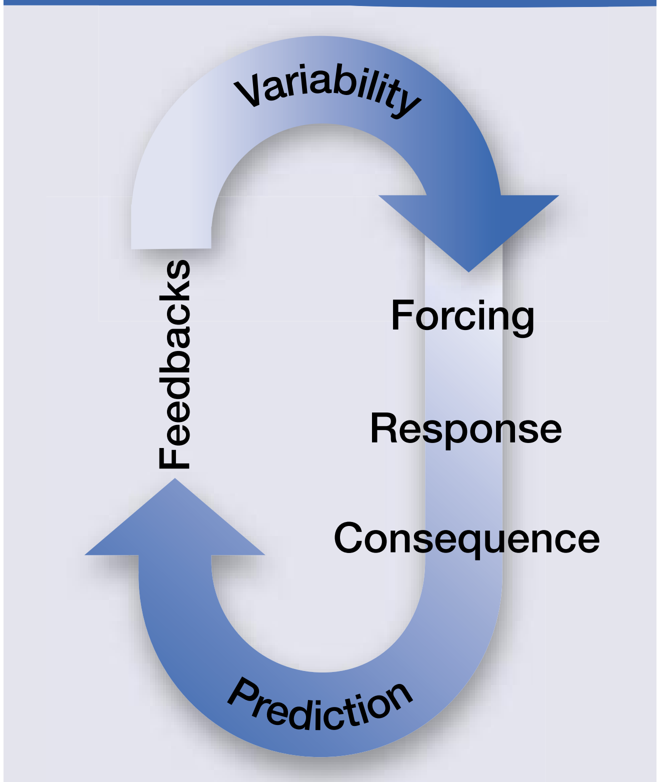
NASA's Earth observations and research focus on the Earth as a system—a dynamic set of interactions among continents, atmosphere, oceans, ice, and life. This way of studying the Earth is critical to understanding, for example, how global climate responds to the forces acting upon it. From the 1960s through the 1980s we developed the technology to view the Earth globally from space, focusing on individual components of the Earth system. This launched an era of rich scientific discovery, including the discovery of the processes behind Antarctic ozone depletion; the Earth's response to incoming solar radiation; and the extent, causes, and impacts of land use and land cover change. In the 1980s and 90s we developed the interdisciplinary field of Earth system science and began to survey the Earth system in its entirety, leading to the deployment of the first Earth Observing System. During this period, scientists used space-based observations, coupled with suborbital and in situ measurements, to uncover the mechanisms behind the El Niño-La Niña cycle and begin modeling the climate system in a meaningful way. For the first time, scientists were able to measure the global distribution of atmospheric aerosols and related changes over seasons and years. In this decade NASA is deploying new types of sensors to provide three-dimensional profiles of Earth's atmosphere and surface. In the decades beyond NASA will migrate current and new sensors to higher orbits to enable higher temporal resolution and interacting constellations of satellites.

NASA's unique capabilities in Earth system science include:

- Creating the ability to study the Earth as an integrated physical and biological system. The Agency is pioneering new remote sensing capabilities from a variety of vantage points. Global-scale changes require a global perspective; local and regional changes can only be fully understood in their global context.
- Addressing fundamental scientific questions with an end-to-end approach that integrates Earth observation, interdisciplinary research, and Earth system modeling, providing comprehensive results to Earth science questions that inform natural resource management, policy and economic decisions.
- Advancing remote sensing technology and computational modeling for scientific purposes, and facilitating the transition of mature observations and technologies to partner agencies that provide essential services using Earth science information.
- Forging domestic and international partnerships to explore the complex Earth system. NASA has the program management and system engineering expertise to help lead complex, multi-partner research endeavors as well as make unique contributions to those led by other nations and organizations.

NASA's Earth science programs are essential to the implementation of three major Presidential initiatives: Climate Change Research (June 2001), Global Earth Observation (July 2003), and the Vision for Space Exploration (February 2004). The first is the subject of the U.S. Climate Change Science Program (CCSP). The second is related, and focuses on national and international coordination of Earth observing capabilities to enhance their use in meeting important societal needs. An Earth Observation Summit in Brussels in February 2005 will adopt a ten year plan for a Global Earth Observation system of systems. The third initiative uses NASA's observing technologies and knowledge of Earth as a planet to aid in the Nation's exploration of worlds beyond.

Figure 1.1



Variability through forcing, response, consequences, and prediction form a fundamental paradigm underlying NASA Earth science research.

From the first weather satellite in 1960 to today's comprehensive Earth Observing System, NASA's view of our home planet has improved life on Earth. As NASA extends exploration of the Earth, Sun, solar system, and the universe, Earth observations and our increasing understanding of the Earth system will shape investigations elsewhere, providing the basis for searching for life elsewhere and for extending life beyond our home planet. Thus, while understanding and protecting our home planet is an essential element of NASA's mission, the Vision for Space Exploration opens opportunities to link Earth observations and research to missions across the solar system and beyond.

NASA provides accurate, objective scientific data and analyses to advance our understanding of the Earth system and to help policy makers and citizens achieve economic growth and effective, responsible stewardship of the Earth's resources. Earth science research aims to acquire deeper scientific understanding of the components of the Earth system, their interactions, and the consequences of changes in the Earth system for life. These interactions occur on a continuum of spatial and temporal scales ranging from short-term weather to long-term climate and motions of the solid Earth, and from local and regional to global. The challenge is to predict changes that will occur in the next decade to century, both naturally and in response to human activities. To do so requires a comprehensive scientific understanding of the entire Earth system, how its component parts and their interactions have evolved, how they function, and how they may be expected to further evolve on all time scales.

Following from the fundamental question above, five scientific questions drive Earth science research NASA:

- How is the global Earth system changing?
- What are the primary causes of change in the Earth system?
- How does the Earth system respond to natural and human-induced changes?
- What are the consequences of change in the Earth system for human civilization?
- How will the Earth system change in the future?

These core questions represent a paradigm of variability, forcing, response, consequences, predictions, and the processes that link these and maintain feedbacks within the Earth system (figure 1.1). This conceptual picture is deeply imbedded within NASA's research strategy to understand changes in the Earth system. While contributing toward and taking advantage of a rapidly developing system of Earth observations, a broad program of NASA research and development addresses these questions, both from an Earth system perspective and within traditional scientific disciplines.

NASA recognizes that environmental variability and change have enormous societal consequences and that people are no longer passive participants in the evolution of the Earth system but instead cause significant changes in atmospheric composition, land use and land cover, water resources, and biodiversity. The fundamental principle that the Earth can only be understood as an interactive system of complex and tightly coupled components including weather and climate, water and energy cycles, global biogeochemical cycles, as well as surface and solid earth processes guides NASA in its efforts to understand and protect the planet we inhabit. This concept of Earth system science mandates a strong interdisciplinary approach to understanding the interactions between the Earth system components.

We live in the extended atmosphere of an active star. Solar radiation drives numerous processes within the Earth system that are crucial for life and the maintenance of Earth's ecosystems. Further exploiting observations and investigations of the Sun-Earth connection is particularly important to understanding Earth's climate and biosphere. Earth and planetary science share a wealth of common understanding about fundamental processes and utilize not only similar instruments, sensors, and platforms but common models and analysis approaches as well. Interdisciplinary Earth, planetary, and space science missions can evolve an even broader view of coordinated observations in space that mesh Earth, Sun, and planetary observing systems and analyses to provide a far broader view of life on Earth and perhaps elsewhere in the universe. Subsequent editions of the Research Plan will more fully embrace the Sun-Earth connection.

This Research Plan describes the fundamental questions that underlie NASA Earth science research, the approach to addressing these through Earth observations, modeling and analysis to diagnose and predict change, the strategy for setting research priorities and for enabling work to address these, and the programs of measurements and modeling envisioned.

Figure 1.2